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FINAL REPORT

RESEARCH ON LEARNING STRATEGIES AND HANDS-ON TRAINING IN CAI

November 1978

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ACKNOWLEDGEMENTS

Joseph W. Rigney conceived of and directed the research described in this report. His death on September 25, 1978, was a great loss to all who had worked with him and to scholars in his fields of research. We at Behavioral Technology Laboratories owe great debts--intellectual, professional, and personal--to Joe Rigney.

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I. INTRODUCTION

This report covers a period of three and three-quarter years, from 1 January 1975 to 30 September 1978. The work performed during this interval was concerned with two major research areas: instructional theory and development of a maintenance trainer-simulator. The projects related to instructional theory were visual analogies of abstract concepts, Markov decision models for instructional sequence optimization, electrophysiological correlates of cognitive processing, cognitive strategies for text processing, and heuristic techniques for logical problem solution. The research on these instructional theory topics was primarily conducted in laboratory environments. The research on maintenance trainer-simulators included testing of the research products in Navy school environments.

During this period, 14 technical reports, seven chapters in books and publications in professional journals, and nine papers for professional meetings were produced. The maintenance trainer-simulator developed and tested under this contract is currently being adapted for use in Navy Class C schools, under a contract sponsored by the Navy Personnel Research and Development Center and the Defense Advanced Research Projects Agency. Further applications for the trainer are being investigated.

BTL research on instructional theory during the almost four-year period of the contract reflects an increasing awareness of advances in cognitive processing theory. This research represents an attempt to apply these advances to instructional contexts. Cognitive models and

experimental results guided the evolution of our research in this area. With the exception of the work on Markov models for instructional optimization, all five of the projects carried out on instructional theory were influenced by cognitive psychology models. In particular, the recent work on strategies for text processing was guided by a cognitive processing model, developed in a schema theory framework, of the reading process.

BTL research has also been influenced by advances in instructional delivery technology. Moving with the rapidly evolving computer industry, more powerful yet smaller computer systems have been employed. In some cases, BTL staff designed and built hardware configurations for computer-based instruction that are only now being offered off-the-shelf by computer companies or peripheral manufacturers. (For example, a computer interface to control a microfiche projector was developed in our laboratory before any were made available commercially.) Although some of the research done under this contract made use of a large time-share computer system specifically designed for CAI (the PLATO IV system), there has been a trend for our research to move away from the use of such large systems toward single-user disk-based microcomputer systems. Future BTL efforts are likely to continue to exploit the low-cost, reliability, and availability features of such micro systems. In addition, much of our future work will exploit the new software transportability features of the UCSD Pascal operating system.

In the remaining sections of this report, progress in each of six major research areas is reported. The first five topics can be grouped under the general heading of "Instructional Theory and CAI." The last topic deals with the development and testing of the Rigney trainer-simulator.

II. VISUAL ANALOGIES OF ABSTRACT CONCEPTS

Three technical reports and a published paper in the Journal of Educational Psychology (Rigney & Lutz, 1976) described work on the effects of visual analogies from 1975 to 1978. The work was motivated, in part, by a desire to explore the effects of right-hemisphere, imaginal processing on retention of relatively abstract ideas. Mental imagery, it was felt, could be expected to provide a dual-coding of the abstract concepts to be learned, when conjoined with a traditional verbal exposition of the concepts. The existence of such a dual code in the mind of a student was expected to improve the probability of recall of the conceptual material.

The experiments to test these hypotheses made use of special instructional materials developed at Behavioral Technology Laboratories, dealing with electrochemistry. Imaginal and non-imaginal techniques were compared in two contexts: initial acquisition of concepts and rehearsal of concepts for recall. Several study techniques and concept presentation modes were studied, including experimenter-supplied interactive graphics, additional written explanation of concepts, student-generated illustrations, student paraphrases, and mentally generated verbal analogies. The results of the series of studies show that, in the case of initial acquisition of the abstract concept used, experimenter-supplied interactive graphics resulted in significantly better recalls. For post-acquisition practice with the concepts, the most effective means of improving recalls was a method in which students were guided to reconstruct a graphic illustration of the concepts. The results of these experiments suggest guidelines for the use of graphics features in CAI.

TR No. 75

Joseph W. Rigney & Kathy A. Lutz, The effects of interactive graphic analogies of concepts in chemistry, May 1975.

Recent advances in knowledge about the different information processing functions of the right and the left cerebral hemispheres, and laboratory studies of these different functions were reviewed for their implications for training and education. The evidence is that the right hemisphere is specialized for spatial and topographic imagery processes, while the left is specialized for serial, analytical, language processes. The two hemispheres have different degrees of access to the vocalizing system on the midline, which is primarily under the control of the left hemisphere, and to the motor systems for the right and left hands. Under certain conditions, the left hemisphere can override control over these systems by the right. The task that is given to the subject, the orienting task, not only determines the subsequent information processing done to mediate responding, but also influences where this processing is done in the cerebral hemispheres. Recent studies of the effects of mental imagery on learning and memory predominantly find strong positive effects. In verbal learning whatever mental imagery adds, a spatial organization, an integrating context, or a second coding, it is clear that it results in better retention and recall in the laboratory.

The implications of this for training and education are that the right hemisphere functions have been relatively neglected in the predominantly verbal mediation of instruction and knowledge. The challenge to instructional technology is to utilize the dual-coding system more effectively.

The first of several planned studies, using interactive, animated graphics for illustrating the abstractions, concepts and laws of science, and for stimulating imaginal processes in students, is described in this report. It was found that these graphics did have positive effects on the learning of concepts in electro-chemistry, as measured by recall tests of knowledge, comprehension, and application, and that the lesson containing these graphics was more attractive to students than a lesson in which purely verbal explanation was used. Subjects who took the lesson providing external imagery reported experiencing more internal imagery than did the subjects who received the verbal version.

These positive outcomes encourage further research into (1) better methods for inducing mental imagery in students than verbal instructions, (2) theoretical foundations for the processing of external imagery relating it to current theories of the structure of long term memory, and (3) objective indicators of mental imaging that would be more reliable than verbal reports of subjects.

TR No. 79

Joseph W. Rigney & Kathy A. Lutz, The effects of interactive graphic analogies of concepts in science, August 1976.

In this series of three studies, interactive graphics, using the plasma panel, touch panel interface of the PLATO system, were used to simulate the topography and functions of a battery, to teach elementary concepts in electrochemistry. The effects of these graphics were compared with verbal descriptions of the topography and functions, in otherwise equivalent lessons; and with playing checkers for the same amount of time as used by postlesson conditions requiring subjects to reconstruct the graphic simulation from memory, or to attempt to imagine mental images of these graphics. The principal conclusions supported by the results of these studies are as follows:

1. As used here, interactive graphics were rated by students to be a more interesting way to present information about abstract concepts in science, and therefore may have received more attention during acquisition than did a purely verbal mode of presentation. When corrected for the effects of prior knowledge, mean scores on verbal and graphics posttests were slightly, but significantly higher for lesson and postlesson conditions containing interactive graphics. Mental imagery could be another source of these effects. Students in Experiment I did report that the graphics in the lesson induced mental imagery while they were taking the lesson. However, the attempts of students in Experiment II to recall mental images of lesson material did not increase scores on the posttest, in comparison to the control group.

2. Interactive graphics, as used here, evidently are most effective during initial acquisition. Requiring students to reconstruct the graphic simulation after the initial lesson contributed less to verbal posttest performance. However, this postlesson condition did result in the acquisition of additional information, reflected in higher scores on a graphics posttest in Experiment III. These results suggest that both shallow and deep processing, in the Craik and Lockhart sense, were induced by this postlesson condition.

3. The fact that students were able to deal with both topographic and abstract conceptual information in either verbal or graphic form, suggests either the same deep structures in LTS, or rapid transformation of different structures in LTS into a common representation when necessary. The current version of semantic network theory of Long Term Memory (Rumelhart and Ortony, 1976), gives a plausible account of this capability in terms of a common basis for storage and processing of both graphic and verbal information.

4. It should be pointed out that these studies dealt with fixed effects variables, and that there are many other relationships between graphics and verbal modes of presentation that were not explored here.

In some of these, one mode would complement the other, so that both would be required to convey the essential information or to enable the desired performance. Such would be the case where interactive graphics are used to represent the front panels of equipment and students operate on these interactive graphics in ways analogous to operating on the actual equipment front panels. Or, the graphics might contain information only referred to verbally, a common usage for diagrams or photographs in texts.

In other cases, the dynamics of processes might be so complex that verbal description becomes too long and clumsy. Animated graphics would allow the student to attend to different parts of the animation at will, and rapidly comprehend the implications of the analogy or metaphor. The internal workings of a transistor come to mind as an example. Here, it might be advantageous to depict electrons and holes "flowing," junction phenomena changing, and the "flow" of currents in forward and reverse biased loops all at once, so that the student could integrate these events rather quickly into an overall comprehension of how a transistor works. In this case, simultaneous animation of many related events would be a unique contribution to dynamic graphics, since verbal description is necessarily serial. This usage of animated graphics would, however, require a plasma panel capable of writing and erasing at higher data rates than currently available.

TR No. 82

Kathy A. Lutz & Joseph W. Rigney, The effects of student-generated elaboration during acquisition of concepts in science, September 1977.

This is the last of a series of studies of experimenter and student supplied cognitive strategies for acquisition and retention of concepts in science. A lesson in electrochemistry was used as the subject matter in these studies. The conclusions we believe are warranted by the results of these studies as follows. The most effective strategy for facilitating acquisition consisted of experimenter-supplied, interactive graphic analogies that supplemented verbal description, in comparison to additional verbal explanation. Two explanations for these positive effects would be that these graphic analogies captured the students' attention more effectively, and that they provided an overall structure, by which individual concepts could be interrelated, serving as a type of organizer.

Student-supplied elaboration, in the form of paraphrasing, drawing illustrations, or thinking of verbal analogies for verbally described concepts in the lesson, was less effective during initial acquisition than the experimenter-supplied graphic analogies, and no more effective than using the same amount of time to go through the lesson twice. However, drawing illustrations of concepts in the lesson was the most effective of these elaboration strategies for students with little or no prior knowledge of the subject matter.

After acquisition coding has occurred, the most effective strategy investigated in these studies was a postlesson review in which students were required to reconstruct the complete graphic illustration of the electrochemistry of a battery, by touching appropriate spots on the display screen. This review may have forced the students to do processing that integrated the various electrochemical concepts. Attempts to induce students to review the lesson by generating mental imagery in which they visualized the flow of events in a battery was not an effective review strategy.

III. MARKOV DECISION MODELS FOR INSTRUCTIONAL SEQUENCE OPTIMIZATION

Two technical reports extended an earlier model (Wollmer, R. D. A Markov Decision Model for Computer-Aided Instruction. Los Angeles: University of Southern California, Behavioral Technology Laboratories, December, 1973, Technical Report No. 72), produced under ONR Contract N00014-67-A-0269-0025. This research was conducted from the onset of the contract until March 1976. The first of the two reports was designed to evaluate the Wollmer model in a CAI context. Two experiments were performed to test the effect on learning of using the model to optimize practice schedules. The results did not reveal a significant improvement in amount learned when the optimization system was used. These results suggest, first, that number of practice trials may be less important than other factors for complex tasks, and, second, that complex tasks may require very large numbers of practice trials to ensure significant practice effects.

The second technical report, which was the last in the series, further developed and refined the Wollmer approach. A mathematical treatment of partially observable Markov desision processes using an infinite planning horizon was developed. Although the system was developed for computer-aided instruction applications, it has wider applicability.

TR No. 76

Richard D. Wollmer & Nicholas A. Bond, Evaluation of a Markov-decision model for instructional sequence optimization, October 1975.

Wollmer's Markov Decision Model for instructional sequence optimization was investigated in a computer-assisted instruction (CAI) context. Two special CAI programs served as vehicles for testing the model; one program (K-laws) taught the students to solve DC circuit problems using Kirchhoff's Laws; the other (TRIG) gave practice in manipulating the six trigonometric ratios. The K-Laws course had elevan stages or levels; TRIG had five; both courses were arranged in a hierarchical order. The Wollmer model requires that transfer would occur from one stage to the next in a hiearachical learning sequence, and that these effects could be estimated so as to produce an optimal training schedule. To determine the effects of additional practice, half the calibration sample was required to finish one successful trial and half were required to have two successes, before moving on to the next stage. Thirty subjects took the K-Laws course, 80 completed TRIG. Instruction was given at individual CAI terminals.

All subjects finished the course, and learned to perform satisfactorily the final criterion behaviors. Practice effects were unexpectedly slight; people who had one success at each stage of the course had about the same criterion-problem performance as those who had two successes throughout. The average time required to achieve a second success was not appreciably different from that required for the first, and two successes at the immediately preceding level was no better than one, as far as transfer to the next higher stage was concerned. These results indicated that the Wollmer hierarchical model could not improve overall learning much by "optimal" scheduling of practice.

One implication of the findings is that in complex learning hierarchies where the top or most difficult task consists of a collection of previously-learned skills, performance time on that top task may be more dependent on the number of subskills involved than upon the number of practice trials in preceding stages. Another implication is that if practice and transfer effects are to be significant in learning this kind of hierarchically-structured material, then a very large number of practice trials may be necessary.

TR No. 77

Richard D. Wollmer, Partially observable Markov decision processes over an infinite planning horizon with discounting, March 1976.

This is the last in a series of technical reports concerned with mathematical approaches to instructional sequence optimization in instructional systems. The problem treated here is very closely related to that treated by Smallwood and Sondik (4). Both papers deal with Markov decision processes where the true state of the system is not known with certainty. Hence the state of the system is characterized by a probability vector. Each action yields an expected reward, transforms the system to a new state and yields an observable outcome. One wishes to determine an action for each probability state vector so as to maximize the total expected reward. Smallwood and Sondik (4) solve this problem exactly for a finite time horizon. This report treats the infinite time horizon with a discount factor, using a partial N dimensional Maclaurin series to approximate the total optimal reward as a function of the probability state vector. While this model was developed for computer aided instruction, it is applicable to other situations as well. This model also is of considerable theoretical value.

IV. ELECTROPHYSIOLOGICAL CORRELATES OF COGNITIVE PROCESSING

This line of research, which had begun before the inception of the contract here reported, culminated in July, 1978, in a technical report describing the results of an arduous series of experiments. Special purpose data collection instruments were devised and built, electrical noise shielding was designed and implemented, and special software for data collection and analysis was written and tested.

The goal of the research was to relate electrophysiological phenomena to ongoing cognitive activities. Subjects were required to solve five-letter anagrams. Solution achievement was signalled by pressing a microswitch. Electroencephalographic activity and time to solution were recorded from the onset of each stimulus. Sixty stimulus anagrams were selected from lists of abstractness and usage frequency to form four stimulus groups: 1) concrete/high frequency, 2) concrete/ low frequency, 3) abstract/high frequency, and 4) abstract/low frequency. Analysis of the solution time data showed that abstractness and frequency both had significant effects, with no interaction. Analysis of the electroencephalographic data showed that anagram solution and recognition of non-scrambled words were both followed by a positive shift, which may be related to decision processes.

TR No. 86

Louis A. Williams & Joseph W. Rigney, Electrophysiological correlates of cognitive activity: Event related slow-potentials developed during solution of anagrams, July 1978.

Electroencephalographic (EEG) activity and time to solution were recorded for sixteen human subjects during a task requiring the solution of five letter anagrams. Solution achievement was signaled by depressing a microswitch. The sixty stimulus anagrams were selected from lists of abstractness and usage frequency to form four stimulus groups: 1) concrete/high frequency, 2) concrete/low frequency, 3) abstract/high frequency, 4) abstract/low frequency. Stimulus words were presented to subjects in a randomized order interspersed with a non-anagram recognition word (TANGO) or a blank screen (BLANK). Stimulus presentation was under computer control and displayed upon a computer CRT. Solution time was subjected to an analysis of variance. Abstractness and frequency were both significant. Abstractness had the greater effect upon solution time. There were no interaction effects. Concrete (low abstractness) anagrams were solved more quickly than abstract anagrams, with the effect of frequency of usage additive to solution times. This result was concluded to support, but not confirm a parallel processing hypothesis: conscious processing concerned with anagram letter rearrangement, and simultaneous unconscious processing concerned with retrieval of possible solution words from long term memory.

The EEG was analyzed by Fourier methods to determine frequency and amplitude content. A coherence analysis was performed upon selected segments of the EEG pre and post response. Visual analysis of individual trials was accomplished through a computer developed super-imposition display. Displayed trials were organized by correct or incorrect solutions, failure to achieve solution (TIME-OUT), TANGO or BLANK presentations. The development of a negative shift following stimulus onset in all except BLANK trials was revealed. Trials in which a correct solution was achieved, or TANGO recognition occurred, showed a reactive shift to positivity at about 350 milliseconds latency. This identification was supported by the analysis of coherence. The negative shift was concluded to be similar to the Contingent Negative Variation (CNV). The positive shift was concluded to be a P300 wave. The CNV-like shift was related to selective attention-selective responding demands of the paradigm. The P300 was related to decision processes allowing a relaxation of attention and responding.

V. COGNITIVE STRATEGIES FOR TEXT PROCESSING

Work in this area was carried out from January of 1976 to the end of the contract. Four technical reports and four chapters in books describe the results of the research. (The last of these reports, Tech. Rep. No. 85, was co-sponsored by the Defense Advanced Research Projects Agency under contract N00014-77-C-0328.) These technical reports mark four stages in the inception of a large effort to understand the nature of some of the higher cognitive processes involved in reading and to apply the findings to the development of training programs for job-related reading.

In the first of the four reports (Tech. Rep. No. 78), an extensive survey was made of many recent trends in cognitive science and neuroscience which could be expected to have an impact on instructional theory and practice. One of the many concepts introduced in this paper was that of the relevance of text-type to reading in general and job-related reading in particular. It was suggested that not all texts are of the same type--they have different structural and semantic characteristics which can be expected to have implications for what and how much of the information they contain will be remembered after reading. The second report in this series (Tech. Rep. No. 80) expanded upon this theme, presenting a theoretical viewpoint on the role of text-type perceptions in reading. A number of reading strategies were discussed within the theoretical context propounded. In the third paper (Tech. Rep. No. 81), the theoretical underpinnings of the preceding paper were examined in greater detail. The theoretical framework was extended to cognitive

tasks other than reading, as well. In the fourth report of the series (Tech. Rep. No. 85), the theoretical mechanisms developed in previous reports are applied to a particular experimental situation and predictions for the memorability of propositions in different types of texts are made. The results of a series of experiments designed to test these predictions are reported, the analysis of which supports the major aspects of the theory. The experimental results suggest that the theoretical approach may serve to generate useful reading strategies, sensitive to the type of text being read, which can improve learning from texts of different types significantly.

TR No. 78

Joseph W. Rigney, On cognitive strategies for facilitating acquisition, retention, and retrieval in training and education, May 1976.

The idea that students could be taught to be more effective learners, in distinction to being taught subject matter, is explored in relation to recent advances in the cognitive and neurosciences, with the objective of integrating information from these sources into a unified viewpoint that could serve as a roadmap for research and as a context for discussion.

According to this viewpoint, cognitive strategies for facilitating acquisition, retention, and retrieval of information and of performance are composed of specifications, called orienting tasks, for how cognitive processes are to be used, and of cognitive processes drawn from representational, selectional, and self-directional resources. Representational resources include propositional and appositional processes of the left and right cerebral hemispheres, chiefly language and imagery. Selectional resources consist of attentional and intentional processes. Self-directional resources include self-programming and self-monitoring processes. Possibilities for teaching students better control over attentional and intentional processes, by using neurophysiological indicators, particularly to reduce self-generated distractions during learning, are noted.

Concepts of processing capacity, depth of processing, expended processing capacity, resource-limited and data-limited processing, top down-bottom up processing, and graceful degradation of output, advanced by several different theorists, are considered in terms of possible sources of individual differences, possible electrophysiological indicators, and implications for cognitive strategies. The importance of long term memory in learning is recognized. Three types of long term store (LTS); semantic, episodic and motor, are described. Semantic and episodic LTS are of great current theoretical interest. Their implications, particularly of semantic LTS, for acquisition, retention, and retrieval are discussed. Norman's concept of web-learning is an example. The additional requirement for some kind of LTS for controlling skilled performances is noted, and two recent theoretical formulations of cerebral-cerebellar roles in this regard are reviewed.

Several kinds of subject-matter are described under information and performance and these are tentatively cross-classified with types of long term memory and strategies for acquisition, retention, and retrieval. Different approaches to teaching students cognitive strategies are described in terms of possible combinations of instructional control and explicitness of the strategy. Finally, techniques for implementation of appropriate approaches are considered. The Learning Assistance Center (LAC) concept is viewed as the context for applying implementation techniques in a systematic and long-term fashion; including diagnosis of individual student requirements and resources, prescription of an appropriate combination of strategies, and instruction in how to use them. It is proposed that LAC's might eventually be recognized as important resources in Naval training.

TR No. 80

Joseph W. Rigney & Allen Munro, On cognitive strategies for processing text, March 1977.

Current research on reading is hampered by the lack of a framework within which to study the effects of a reader's prior knowledge on his or her processing of an unfamiliar text. As a result, most reading research has emphasized perceptual rather than conceptual processing during reading. Evidence is cited in support of the claim that various types of prior knowledge play important roles in understanding during text processing.

Recent developments in cognitive psychology and artificial intelligence have resulted in a new kind of model for conceptual processing, called procedural semantics. In this report, a framework is laid for the application of the procedural semantics formalism to the analysis of conceptually-driven processing in reading. According to this theory, two different types of conceptual processing units (called schemata) are responsible for conceptually-driven processing in reading. One type is the form-schema, which accounts for the

syntactic or formal expectations which people make use of in text processing. The other type is the content-schema, which accounts for the nature of readers' semantic expectations. Models for a small number of specific form- and content-schemata are proposed, and certain experimental and observational evidence is explained in terms of these models.

Implications for effective reading strategies for adult reading are derived from the premises of the model. Several different kinds of reading strategies are characterized in terms of the model. When readers employ single-pass strategies, they process the text in a strictly linear, left-to-right fashion. This approach makes minimal use of the potential for conceptually-driven processing that could be achieved through the activation of some high-level schemata. In exhaustive multi-pass processing, the first pass results in the activation of a number of form- and content-schemata which can serve as an aid in subsequent passes, deriving expectations about the form and meaning of what is about to be read. This technique can often be wasteful of resources, since it does not actively direct processing toward what is most important or least well understood. Extractive multi-pass processing reflects a more efficient strategy for reading an entire text. By using this technique, a reader "skims" the text in a selective way on repeated passes, building up such a complete understanding of the meaning of the text that the final reading of the text is often a process of merely filling in the gaps in understanding. This technique is often effectively used by graduates of adult reading improvement classes. Selective, multi-pass strategies characterize the reading of those who know what it is they want to know, and who are under no constraint to learn all that might be learned from a text. In this type of text processing, the reader begins the task with the intention of acquiring some specific information. As a result, a number of specific content-schemata are activated and are used to guide the order and the selection of those portions of the text to be processed.

Several potential applications are suggested by the consequences of the theory for conceptually-driven processing in reading presented here. These include possible uses for headings in texts, means for constructing advance organizers for texts, and training readers to make more effective use of texts by being sensitive to their motivating tasks and by exploiting their capacities for generating expectations about the meaning of the texts through conceptually-driven processing.

TR No. 81

Allen Munro & Joseph W. Rigney, A schema theory account of some cognitive processes in complex learning, July 1977.

Procedural semantics models have diminished the distinction between data structures and procedures in computer simulations of human intelligence. This development has theoretical consequences for models of

cognition. One type of procedural semantics model, called schema theory, is presented, and a variety of cognitive processes are explained in terms of the theory. In schema theory, the flow of processing control is determined not by a central monitor, but by interactions among the conceptual entities (schemata) that make up the model. Schemata interact by providing activation resources to each other.

Instantiation is the special process whereby a partial copy of a strongly activated schema is created. In this copy, the variables of the schema are filled with particular values. Such copies make up specific or episodic memory. The schemata on which they are based comprise generic or semantic memory.

Many of the phenomena of consciousness and of short-term and long-term memory are explained on the basis of the activation processes of schema theory. Unactivated schemata are equivalent to all the unconscious knowledge in a person's long-term memory. Schemata that are activated, but are below the threshold of instantiation, are in a preconscious or subconscious state. Those schemata that are more fully activated, that are above the instantiation threshold, are the stuff of conscious thought, and may be thought of as roughly equivalent to the contents of short-term memory.

Conscious cognitive strategies are treated as the activations of abstract prescriptive schemata. A treatment of creativity is presented, along with the outlines of an approach to individual differences in creativity. The effects of orienting tasks are explained in schema theory, and the relationship between orienting tasks and self-direction in complex learning and problem solving is discussed.

Inference and depth of processing receive related schema theory treatments. Both concepts are treated in terms of the extent to which activation spreads to include related schemata. In general, the more schemata activated to the level of instantiation by some datum, the more deeply processed that datum is. Inference is seen as a kind of delayed deeper processing.

Types of insight phenomena from several contexts can also be treated in schema theory. Each type of insight involves the instantiation of one or more new schemata that take some pre-existing concept in memory as a parameter.

Three dimensions for distinguishing or comparing schemata are proposed: function, abstractness, and scope. The contrasts between multi-store models of cognition and schema theory are summarized.

TR No. 85

Lynn Gordon, Allen Munro, Joseph W. Rigney, & Kathy A. Lutz, Summaries and recalls for three types of texts, May 1978.

A theoretical orientation for the study of different types of texts is presented. Schema theory is proposed as a useful meta-theory within which to develop specific theories about reading. Both theories about processes of reading and theories about the structure of what is read can be readily formulated in schema theory terms. It is proposed that readers make judgments about the types of texts that they read and that these judgments bring about the activation of expectations with respect to the structure and meaning of these texts.

Previous work on the structure of texts, primarily for simple narratives, is reviewed. Problems with earlier formalisms and scoring methods are discussed, and heuristics for avoiding these problems are presented.

Three types of texts were selected for study. One type was the simple short story, a type closely related to (and, in some cases, identical with) the kinds of texts studied by other researchers. The second type studied were instructions. The third type was definitional explanations, a type well characterized by popular science articles. Detailed analyses of the text structures and text semantics for eight texts (three stories, two instructions, and three definitions) are presented. Texts of the different types differ from each other in consistent ways on two dimensions. First, the text structures of definitions tend to be organized horizontally rather than vertically, as are the text structures of stories and instructions. Second, the semantic representations of stories are composed of specific concepts, in schema theory terms, while the semantic representations of instructions and definitions consist primarily of generic concepts. On the basis of these differences among the texts, we predicted that stories would be better remembered than instructions, which would, in turn, be better remembered than definitions. Three experiments were conducted to test this hypothesis.

In Experiment 1, subjects read and summarized six texts and later recalled three of these texts. Analysis of the summary data indicates that texts of different types are summarized to about the same extent. The recall data, however, suggests that text type may determine the amount recalled. Analysis of the recall data showed that, although stories were remembered best (as had been predicted), the propositional content of definitions was remembered better than that of instructions. It was hypothesized that rereading and summarizing may have had a differentially facilitative effect for later recall, benefiting the recall of definitions more than instructions.

In order to test this hypothesis, Experiments 2 and 3 were performed. Subjects heard tape recorded texts (in Experiment 2 the same set of texts used in Experiment 1; in Experiment 3 a somewhat different set), and, after performing a brief interfering task, recalled each text after hearing it. They were therefore not able to reprocess texts as they had been able to in Experiment 1. In general, the results of these experiments confirmed our predictions: stories were recalled better than instructions, which, in turn, were recalled better than definitions. Subjects' recalls in these experiments were also scored for the amount of reordering of the textual material. This analysis showed a very powerful effect due to text type. Recalls of definitions showed significantly more reordering than did recalls of instructions, which, in turn, had more reordering than did the recalls of stories. These results are also in accord with our theory that stories have more hierarchical, differentiated text structures than do instructions or definitions, and that definitions have less hierarchical structures than do instructions.

Subjects in these two experiments were also requested to cluster the texts in natural groups according to their types, as they perceived them. Their groupings were remarkably consistent with our own classifications.

The research presented demonstrates the need for a more thorough investigation both of the nature of people's expectations for differences in different types of text, and of the effects of such expectations on understanding and memory. Further research is also needed to explore the hypothesis that texts of different types may benefit differentially from the application of particular learning strategies, such as re-reading and summarizing.

VI. HEURISTIC TECHNIQUES FOR LOGICAL PROBLEM SOLUTION

This research effort was pursued from February of 1977 to June 1978. Ongoing BTL interest in the nature of cognitive processing during troubleshooting activities motivated a series of studies on how people solve verbal logic problems. Two technical reports were produced. The first report describes an initial evaluation of two computer programs designed to aid human problem solvers. Experience with these programs and with the introspective reports of logic problem solvers led to the posing of two basic questions: first, what factors in these problems are predictive of their difficulty, and, second, what strategies can be taught to improve problem solving performance? The experiments reported in the second technical report (No. 87) provided partial answers to these questions. It appears that one of the most important predictors of success in the solution of these problems was the subject's ability to convert the verbal representation to some more logically manipulable representation. Those problems which were couched in such a way that such a translation was made more difficult were harder to solve. A training system for improving logic problem solution was devised and tested. Experimental results show that use of the techniques did improve performance. Future efforts in this domain should concentrate on transporting the training system attributes to a real-world domain, such as electronics equipment troubleshooting.

TR No. 83

Nicholas A. Bond, Jr., William T. Gabrielli, & Joseph W. Rigney. Studies of verbal problem-solving: I. Two performance-aiding programs, August 1977.

Two computer programs were written to provide on-line aiding to human problem solvers. Both programs were written in time-shared BASIC, and were designed for "membership" problems. In this kind of problem, there are several English sentences and implicit in the sentences are various relations; the task is to infer a membership structure that is compatible with all the logical constraints. Membership problems may be cast in various settings, such as a murder mystery where a culprit is to be identified.

One program (FIRST) was based on Findler's "Universal Puzzle Solver" concept; the other (GABE) used Wang's theorem-prover logic. In both programs, the human operator converted English problem sentences to logical membership relations. The programs kept track of all relations entered, indicated when more data inputs were needed, and scored whether a correct answer was achieved.

Of the two programs, FIRST appears to be most feasible with ordinary college subjects. It accepts logical inputs in a near-English format, and shows current logical status of a problem via tabular arrays of X's and O's. The present version of GABE used a strict "p, q, r" logical notation; college subjects find this difficult and unsatisfactory.

The structure of the FIRST program suggests a "depth-of-inference" measurement technique. When all possible logical paths in a membership problem are known, the "depth" of any given node in the path can be obtained from probability-of-success numbers at that node; also it appears that a subject's logical progress along a path can be computed and displayed. Further empirical work will explore the usefulness of such depth measures for scoring individual performances, and for teaching problem-solving heuristics in technical materials.

TR No. 87

Nicholas A. Bond, Donald McGregor, Kathy Schmidt, Mary Lattimore, & Joseph W. Rigney, Studies of verbal problem-solving: II. Prediction of performance from sentence-processing scores, June 1978.

In complex reasoning problems of "the who-done-it" type, four distinct solution processes were identified:

(1) intra-sentence or word-into-symbol processing, where the solver converts the verbal information into strict logical relations;

(2) inter-sentence processing, where the subject has to combine the logic from two or more sentences in order to obtain new inferences;

(3) ordering of problem variables into some rank or numerical ordering scheme;

(4) collecting the logical relations into a reliable format that will reduce the memory load and facilitate the "where-to-look-next" decision.

This study explored the extent to which separate scores on these processes could predict performance on difficult problems.

Scores on the sentence-logic items correlated well ($r=.68$, $N=34$) with number of reasoning problems solved, as did the ordering score ($r=.75$). These scores, then, presumably are "closer" to the actual performance than are verbal scores such as McGraw-Hill Reading Rates ($r=.40$ to $.50$). Individual timing of inference responses showed that subjects often had long pauses during inter-sentence processing, whereas intra-sentence responding was relatively fast and regular. The inter-sentence portions of the performance appeared to be key discriminators between success and failure.

A small training experiment was carried out with seven new subjects, who were matched on reading scores with the previous group. These subjects were given six hours of intensive, individual practice on the four processes; a standard matrix format was used, and five rules and heuristics were taught which were supposed to facilitate inter-sentence reasoning. The trained people did show improved sentence-logic scores (median about 40% over the comparison group); and if a large reasoning problem contained only straightforward sentences, then the training was very effective. In fact, all seven subjects solved correctly a 4-dimension, 5-variable negative-disjunction problem within a few minutes. For those problems which hinged upon appreciation of verbal subtleties, though, the training did not help at all.

The investigation supports the idea of rapidly teaching some "logical tricks" in higher-order cognitive operations; but the special training only works if the problem material is clean and unambiguous. One obvious extension of the study is to see if the same increase in performance can be produced in a practical-reasoning domain such as troubleshooting of digital devices; another extension is to look more closely at the verbal subtleties which so effectively prevent solution of some large problem.

VII. MAINTENANCE TRAINER-SIMULATOR DEVELOPMENT

Work in this area proceeded throughout the term of the contract, building upon previous research on computer-controlled trainer simulators done at BTL under ONR/ARPA funding. Two technical reports were produced. These reports describe a revised trainer-simulator called the Generalized Maintenance Trainer-Simulator (GMTS), and report on two field evaluations of the system. The present contract supported the development of the GMTS system and programming. Development of data bases and the conduct of the field tests were jointly sponsored by ONR and by the Naval Personnel Research and Development Center.

The philosophy of the GMTS system is that there should be a relatively low-cost, stand-alone system for intensive practice in troubleshooting. Furthermore, the hardware and software should be general-purpose. That is, it should be possible to enter a data base for a new piece of equipment and provide students with practice on the new equipment without making changes to the hardware delivery system or the GMTS programs. The two technical reports produced, taken together, constitute evidence that GMTS has this general nature. The system was used first to provide practice in systems level troubleshooting in the UHF communications side of the Fleet Communications System. The system was tested with this data base on twenty students about to enter class C schools. The second evaluation of the system was performed with the AN/SPA-66 Radar Repeater; ten subjects used this system for troubleshooting practice, then worked actual troubleshooting problems inserted into an AN/SPA-66 equipment. In both cases the same hardware and GMTS program was used, but with different data bases.

Development work is now proceding, under the sponsorship of NPRDC and ARPA, to convert the GMTS system to current generation hardware, to develop a new data base, and to implement and test the new system in a Class C school environment.

TR No. 89

Joseph W. Rigney, Douglas M. Towne, Carole A. King, & Patrick J. Moran, Field evaluation of the generalized maintenance trainer-simulator: I. Fleet communications system, August 1978.

The Generalized Maintenance Trainer-Simulator (GMTS) is a concept for giving students in Class C schools intensive practice in troubleshooting equipment and systems taught in those schools. It can be used for any device in which signal paths and their relationships to controls, indicators, and test points can be defined. The GMTS uses generative CAI. That is, it generates the interaction with the student by referring to his last inputs and to its stored history of interactions with him up to that point. To the extent that these individual student histories constitute models of individual students, GMTS constructs a model of each student to interact with that student. In addition to these features, GMTS is uniquely suitable for use in Class C school training. The computer program that implements the instructional system is indifferent to the specific equipment being taught. What specific equipment that is simulated by the GMTS is determined by loading two data bases for that equipment: one describing essential internal features of the equipment and the other describing the external features.

This is a report of a field evaluation of the GMTS applied to systems level troubleshooting in the UHF communications side of the Fleet Communications System. Twenty Class A school students waiting to enter C schools practiced solving thirty-five troubleshooting problems. Results were generally positive. The students became uniformly more fluent at troubleshooting; mean times to solve a problem were decreased by a factor of two, and standard deviations of these times were decreased by a factor of five. Also, students' attitudes toward the trainer were generally favorable. An additional field trial is underway, using the AN/SPA-66 radar repeater as the subject matter.

Joseph W. Rigney, Douglas M. Towne, Patrick J. Moran, & Richard A. Mishler, Field evaluation of the generalized maintenance trainer-simulator: II. AN/SPA-66 radar repeater, November, 1978.

This is a report of a field evaluation of the Generalized Maintenace Trainer-Simulator (GMTS) applied to troubleshooting the AN/SPA-66 Radar Repeater.

The GMTS is a relatively low cost, stand-alone system for providing intensive practice in troubleshooting. While GMTS is both hardware and computer software, the computer programs and associated data base represent the essence of the GMTS concept. This concept can be applied to any equipment or system by compiling the particular effects of indicators in various configurations and modes, and by preparing microfiche images of the equipment in a multitude of normal and abnormal states. This information, contained in a data base dedicated to the equipment to be simulated, provides the GMTS program everything necessary to generate and present meaningful interactions with each individual student. Since the program itself does not contain data specific to any simulated system, the trainer-simulator is termed 'generalized.'

This field test was the second to be conducted; the first involved twenty Class A school students troubleshooting the UHF communications side of the Fleet Communications System. A major objective of the second field test was to demonstrate the generality of the trainer-simulator, thus a completely different equipment was implemented. The data base for this target equipment was constructed entirely by two technicians who received brief training in GMTS data base formulation (whereas the data base for the first field test was assembled primarily by the personnel responsible for programming GMTS).

The field test involved ten subjects, each attempting to isolate thirty-three simulated malfunctions over a sixteen-hour period. Following this practice phase the students were tested using an actual AN/SPA-66 with actual, inserted, malfunctions.

As with the first field test, results are generally positive, especially in relation to success in the test phase using actual equipment. Owing to the small sample size, however, this field test is more valuable in assessing the success with which GMTS can implement a wide range of target systems.

VIII. RECOMMENDATIONS

All of the areas of research pursued under this contract have the potential for producing products useful to the Navy. Specific recommendations can be made with respect to five of these research areas, the products of which differ in their current applicability. One of the research efforts, the development of the maintenance trainer-simulator, has yielded a product which is essentially ready for implementation in variety of Navy school environments. The discussions of the five research areas for which recommendations can be made are arranged roughly in order of the immediate applicability of their results, with the most immediately applicable research products discussed last.

Instructional Sequence Optimization

The research discussed in Section III, above, resulted in a system for optimizing an instructional sequence with respect to time in a CAI context. While this method did not presume that time was the only crucial resource for optimization, the work demonstrated the difficulty of experimentally exercizing an optimization technique in which only a sub-set of acknowledged key variables are involved. Other factors which should be included in the objective function include the cost of an instructional sequence, the clarity of targeted concepts in the instructional domain, and performance measures of the student's grasp of the instructional content.

It is to be expected that the armed services, as large organizations responsible for vast amounts of technical instruction, will make increasing use of CAI systems in the future. Features of CAI which will motivate such greater utilization will include low cost, standardized instruction, and the opportunity for time-saving but still inexpensive individualized instruction. As the extent of CAI grows in the armed services it will become ever more important to be able to manage instruction in automatic and cost-effective ways. One aspect of such effective management will be instructional sequence optimization. Although the results of the research carried out to date do not justify an immediate development program to produce a computer-managed instructional system using instructional sequence optimization techniques for the Navy, the potential benefits to be derived from eventually implementing such a system are great. Support of further research in the area, particularly research emphasizing several features of the instructional sequence to be optimized, is indicated.

Heuristic Techniques for Problem Solving

BTL research in this domain, described in Section IV above, has shown that logical problems couched in verbal form may present peculiar obstacles for solution because of that form. This is an issue of concern for the military, because many technical problems and prepared information sources for solving technical problems are presented in a verbal format. A technician who must operate or troubleshoot an electronic device, for example, is likely to talk and think about his actions in qualitative verbal terms. His attempts to validate his

interpretations of the results of his tests of the equipment may be confirmed, guided, contradicted, or frustrated by the information in a verbal format in technical manuals. Our results indicate that with a "clean" problem (that is, one that is well defined and expressed in simple declarative sentences) almost any regular aiding format will assure rapid and accurate solution. This result leads to the practical possibility of requiring technical materials to be written in such a way that the text is "clean."

In the complex verbal puzzle problem domain, a key skill is the identification of phrases which essentially split the problem into smaller and more manageable parts. For instance, if the problem has six variables which have to be sorted or identified in some way, there are often one or two key sentences which permit simple categorization of these variables into subclasses. The skills required to identify and to exploit these high-information sentences have not been studied, but there is reason to expect that such skills are highly developed in the truly expert problem solver. Perhaps the skill is analogous to that shown by the troubleshooter who makes a few rapid narrowing-down checks to attain crude isolation of a malfunction. Once identified and understood, such skills should be explicitly taught to students such as electronics equipment technicians, who must learn to be effective problem solvers.

A second major aspect of the research findings in this area has to do with the use of automatic problem-solving aids. Complex intellectual tasks, such as combining probability information, controlling several aircraft, or troubleshooting electronic equipment could be made

easier for those assigned these tasks through the use of appropriate computer-based aid systems. Such systems would perform many library, calculating, and bookkeeping chores; the controlling humans would, of course, make the decisions and control the course of processing. Our research in this area can be thought of as a first step toward providing automatic systems to aid in logical problem solution. What is required now is an effort to develop such aiding devices for practical military tasks and to test their effectiveness.

Visual Analogies

The research reported in Section II yielded results which suggest applications to the development of CAI technical subject matter courseware. CAI permits the use of interactive graphics displays to help convey the nature of complex processes to students. The results of our research indicate that the use of such displays is most effective for initial presentation of the concepts. Interactive graphics is less useful as a review device for student use. The research has shown that a more effective post-presentation learning activity is guided student reconstruction of a graphic display. This can be accomplished through the use of a touch panel or a sonic pen device, either of which takes advantage of the students' natural pointing responses. Further research is now needed to determine what kinds of complex topics benefit most from interactive graphics presentation and from student reconstruction of graphics. Such findings could then be applied to the teaching of Navy technical subject matter.

The low costs and other attractive features of CAI are likely to ensure increased use of this instructional technique and medium in the

armed services. These features, however, will not necessarily ensure that the most effective use of the capabilities of the instructional computer system will be used. It is possible that, in some cases, attempts will be made to simply transport a traditional training manual approach to the new CAI courses. Such a course would fail to make use of such features as interactive graphics. Our results have shown that this feature can improve learning over a more traditional approach. Further research could be expected to lead to the production of guidelines for the effective use of interactive graphics and guided student constructed graphics. Implementation of such guidelines would then lead to more effective CAI courseware.

Cognitive Strategies for Text Processing

Toward the end of the course of research reported in Section V an unanticipated result was discovered that may have important applications to the use of texts for instructional purposes. The results of three experiments indicated that understanding of and memory for the contents of different types of texts benefit differentially from particular text-processing techniques. For example, memory for texts that have an explanatory nature benefits from the processes of rereading and summarizing texts. Memory for instructional texts is not significantly improved through such techniques. These findings must be thought of as tentative, but if they can be replicated in experiments of the appropriate design, their implications will have obvious applications for military instruction. Either of two methods could be expected to prove the more effective means of using the results to improve learning from instructional texts. Texts could be prepared which incorporate

directions to the student as to which techniques should be applied to each segment of text in order to maximize learning from that segment. Alternatively, students could be trained, in a short course, to recognize texts of each major type and to apply the appropriate techniques. Further research is required before either of these methods could be developed for application in Navy schools. First, more must be learned about the relationships between text type and effective text processing techniques. Second, experiments must be performed to learn whether the improvement in learning from Navy texts brought about through the use of these techniques is sufficiently great to justify the development of an application. Third, it must be determined how these findings may best be applied. The application of the findings of such a research program can be expected to measurably improve the efficiency with which military students learn from technical documents.

The Generalized Maintenance Trainer-Simulator

The generalized maintenance trainer-simulator (GMTS) is the end-product of many years of research funded by the Office of Naval Research and the Defense Advanced Research Projects Agency. The research conducted on this contract has shown that GMTS is an effective way of increasing the amount of troubleshooting practice on particular equipments for Navy electronics students. It also provides the capability of simulating a wider range of troubleshooting experiences that can be provided practically on real equipment. The research has shown that data bases for new types of electronic equipment can be prepared for the GMTS system by subject-matter experts who are not computer programmers. Two field evaluations in Navy schools have shown that use of GMTS results

in more efficient use of students's time and in time savings for Navy instructors, while providing students with extensive practice at low cost.

The GMTS system is essentially ready for general use in Navy Class C schools. Unfortunately, however, in its current implementation it makes use of outmoded and unreliable computer equipment. Behavioral Technology Laboratories began research on a new contract, jointly funded by the Naval Personnel Research and Development Center and the Defense Advanced Research Projects Agency, on September 30, 1978 (N00123-78-C-1457) to (1) develop the GMTS software on current-generation hardware (Terak 8510/A microcomputer), (2) prepare new data bases for the new GMTS system, and (3) to implement and test the effectiveness of the new system in a Class C school. The development of the new software will have special consequences for the future and ongoing usefulness of the GMTS system to the Navy. The new software will be transportable to other computers; therefore, the GMTS system will be protected against hardware obsolescence. This will be accomplished by developing the new GMTS software on the UCSD Pascal operating system, a virtually machine-independent operating system for micro- and mini-computers.

We recommend that, once the initial development phase of the new GMTS system is complete (approximately October 1979), data base development for a variety of Navy Electronic equipments be developed for widespread use in Class C schools. We further recommend that research on the potential usefullness of the GMTS system in Class A schools be conducted. The GMTS system can be expected to serve as an important component of all Navy electronics equipment maintenance training.

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